World Conference on
Timber Engineering
Oslo 2023

DEVELOPMENT OF LVL-CONCRETE COMPOSITE FLOOR SYSTEMS

Alireza Fadai[1], Johann Scheibenreiter[2], Alex Müllner[3], Marie Theres Brunauer[4]

ABSTRACT: The growing enormous number of mid-rise timber buildings in European metropolitan areas leads to the investigation of a possible optimization potential in the use of timber in combination with other building materials. Various timber-based composite floor systems, in particular the combination of laminated veneer lumber products and other conventional building materials, such as conventional or steel fiber reinforced concrete coupled by various sorts of dowel-type or notched connections, are studied. In regard to structural, economical and resource efficiency on overall component level, the extent of interrelationships in the development of multifaceted optimized system solutions can be shown.

This paper shows the results of the feasibility studies and the conceptional design. The objective of the studies is to develop application-optimized multi-layered structural composite floor systems with a special focus on the joint design of the various thereby used connection types between the coupled composite layers. The conceptual feasibility studies illustrate the capabilities in the application of laminated veneer lumber products in composite floor systems. Consequently, the presented results enable engineers, as well as builders and planners, to further strengthen the implementation of timber-based composites within modern building applications. A construction-optimized design with increased resource efficiency can be achieved.

KEYWORDS: Composite structure, Laminated veneer lumber, Steel fiber concrete, Dowel-type connection, Notched connection, Sustainable building

1 INTRODUCTION

In Austria, timber construction has increasingly gained market share over the last twenty-five years. Based on the total constructed usable volume in the building sector, it has increased from 14 up to 24% between 1998 and 2018 [1].

In 2018 (24%) the timber-based building material proportion in housing construction is distributed to 53% (newly built single and multi-family houses as well as extensions and conversions) and 47% in non-residential construction (public, commercial and industrial buildings as well as agricultural buildings). At the residential segment, the proportion of timber-based construction has risen particularly strong with an increase from 10 up to 23% in the mentioned period [1].

Further increases are to be expected, especially for large-volume buildings as residential and public buildings.

The city of Vienna continues to grow and an increasing population means that more living space must be made available. Since land is not available in unlimited quantities and there are some old buildings in Vienna without roof extensions, there is the possibility of extending them and thus creating new living space. As of 2018, it is estimated that approximately 9,300 expandable roofs are available in Vienna [2].

Often, the top floor is designed as a reinforced concrete structure with or without a connect to an existing wooden floor. If steel fiber concrete is used instead of conventional reinforcement concrete, this could lead to a more economical construction method. Thus, with the help of steel fiber concrete and an existing wooden floor, a composite roof can be created in old buildings, which, for example, can be erected economically and increase the structural safety.

Within the framework of the research project the Department of Structural Design and Timber Engineering (ITI) at the Vienna University of Technology (TU Wien) in cooperation with Schmid Schrauben Hainfeld Ltd. developed a multi-layer floor system, composed of concrete connected to timber sections and use advantages of each used building material. Timber-hybrid elements meet modern architecture´s demands and can help to increase the use of timber as building material.

---

[1] Alireza Fadai, TU Wien, Research Unit of Structural Design and Timber Engineering, Austria, alireza.fadai@tuwien.ac.at

[2] Johann Scheibenreiter, Schmid Schrauben Hainfeld Ltd., Austria, johann.scheibenreiter@schrauben.at

[3] Alex Müllner, TU Wien, Austria, alex.muellner@tuwien.ac.at

[4] Marie Theres Brunauer, TU Wien, Austria, marie-theres.brunauer@tuwien.ac.at

https://doi.org/10.52202/069179-0437

2 EXPERIMENTAL TEST EXECUTION

The research project includes design concepts, feasibility studies and performance assessments of the components in order to improve the overall performance. In addition, the development includes experimental investigations of the components in order to improve the overall performance.

2.1 STEEL FIBER CONCRETE

In Austria and Germany guidelines on the use of fiber-reinforced concrete are available. In Austria, this is the "Fiber-reinforced concrete" guideline published by the Austrian Construction Engineering Association (ÖBV) [3] and in Germany the "Steel-reinforced concrete" guideline published by the German Committee for Reinforced Concrete (DAfStb) [4]. These guidelines, which have been introduced by the building authorities, also permit the use of fiber-reinforced concrete. For the connection of wooden beams and fiber-reinforced concrete, fasteners are used, especially in old buildings in the form of self-tapping screws. For the use of these screws, European Technical Assessments (ETA) are required [5]. In previous investigations [6, 7], compression-shear tests were carried out to show the equivalence of fiber-reinforced concrete to normally reinforced concrete. It was confirmed that the investigated lanyards in fiber-reinforced concrete give equivalent results in terms of load-bearing capacity and serviceability. These tests were carried out for steel fiber reinforced concrete, which was qualified according to the Austrian guideline.

2.1.1 Experimental investigations according to the guidelines for fiber-reinforced concrete

In this chapter, the tests carried out according to the Austrian [3] and German guidelines [4] are described and evaluated. The aim of the tests is to show the difference between the two guidelines using the same fiber-reinforced concrete with 25kg/m³ steel fibers and to find a possible correlation between the test results in order to save multiple tests in the future. The background to this is that fiber-reinforced concrete tests are relatively expensive and time-consuming, one test of a concrete-beam takes about 60 minutes and at least six tests are prescribed to state performance [8].

The 4-point bending test itself lasted 20 min per fiber-reinforced concrete bar (Figure 1). This time results from the deformation rates of 0.1mm/min up to 0.75mm and 0.25mm/min up to 4mm deflection. For a better comparison, all specimens are tested up to 4 mm deflection and then the test is terminated. After that, the specimens are "manually" broken in the middle to count and evaluate the number of fibers in the fracture surface.

In addition to the post-cracking tensile strength in the bending tension zone, the compressive strength is also determined using four cube specimens with an edge length of 15cm.

Figure 1: Completed fiber-reinforced concrete testing according to DAfStb guideline

For each specimen, the deflection wis measured using two probes, the applied force and the test time. The bending tests start loading the beams according to the ÖBV guideline [3]. In the first two tests, the measuring frequency is 10Hz, then increased to 20Hz. During the first test, the aluminum angles, which served as stops for the measuring probes, were glued on with a 2-component adhesive. However, one angle came off after the initial cracking, so that control via the displacement transducers was no longer possible and the test had to be aborted. As a result, the aluminum angles are screwed to the bending beams with a 5x30mm dowel in all further tests. Furthermore, in the fifth test according to the ÖBV guideline [3], the test also failed because it was not possible to create a complete force-deflection diagram. In this test, there is a sudden drop in the force after the initial crack and the test is terminated prematurely. For these reasons, only ten complete test results exist carried out according to the ÖBV guideline [3]; for the tests according to the DAfStb guideline [4], all twelve tests are successful. The tests according to the ÖBV guideline [3] are labeled and numbered as sample K1-12 and those according to the DAfStb guideline [4] as sample G1-12.

In general, it can be said that oscillations after the initial crack and the force drop can be observed in the force-deflection diagrams. Figure 2 shows an example of a diagram in which the deviations can be seen.

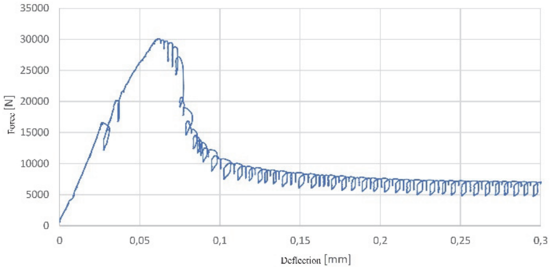

Figure 2: Evaluation of the force-deflection diagram specimen K8 [8]

It can be seen that in a range of 0.005 mm the deflection increases very quickly, although the force is slightly reduced. This is a deformation-controlled test with a deformation rate of 0.10 mm/min and it can be seen from the measured data, that within 50 milliseconds the deflection increases by 0.0037 mm and the force decreases by 40.95 N. Therefore, the deformation speed in this range is 4.40 mm/min.

Subsequently, the force is decreased and the deflection consequently becomes less. After that the force is increased again and in a certain range, there is again a sudden increase in the deflection.

This effect occurs in almost all the specimens tested, both the shorter (ÖBV) and the longer (DAfStb) ones. The reason for this effect is the control behavior of the machine. [8].

Based on the tests carried out, the fiber concrete C25/30 XC2 GK8 F52 ZG1 with a steel fiber content of 25kg/m³ corresponds to classes T2 and G1 according to the Austrian ÖBV guideline [3] and L1-0.6 and L2-0.9 according to the German DAfStb guideline [4]. Based on these classifications, the German guideline results in lower design values. Thus, if a fiber-reinforced concrete is classified with classes T2 and G1 according to the Austrian guideline and designed with classes L1-0.6 and L2-0.9 according to the German guideline, sufficient safety is provided. However, this does not apply in the opposite sense, since the design values of the German guideline are significantly lower.

In summary, it can be said that significantly different design values according to German and Austrian guidelines can be expected for the same fiber-reinforced concrete. For both serviceability and ultimate limit state, the characteristic post-cracking tensile strengths differ, in some cases considerably. Therefore, when converting these values into the design values of the post-cracking tensile strengths, the formulas of the guidelines are adapted to the respective test. The evaluation of a test series according to the respective other guideline makes little sense, since the characteristic values of the post-cracking tensile strengths are almost identical, but the design value, which is decisive, is different. Furthermore, the values of the individual tests scatter very strongly, which makes a general correlation of the two guidelines difficult.

In general, the test results of the DAfStb guideline "Steel fiber reinforced concrete" [4] is more conservative than the Austrian guideline [3].

2.2 CONFIGURATION OF THE JOINTS

The load-bearing behavior of the floor element is not only dependent on the properties of the single composite materials, but also on the configuration of the joints between the timber and concrete-based composite layers. This is the subject of numerous experimental Push-Out tests.

Load-bearing capacity of structures can be increased significantly by the usage of semi-rigid or rigid shear connections (e.g. dowel-type or notched connections) between the timber and concrete composites. By the optimized use of composite materials on joint level as well as on overall component level, not only structural performance can be increased, but also resource efficiency.

For this reason, resource-conserving load-bearing composite structures consisting of various types of laminated veneer lumber (LVL), such as spruce or beech LVL, in combination with different types of concrete toppings, such as conventional reinforced concrete (RC) or steel fiber concrete (SFC), coupled by various types of joints (dowel-type fasteners, notches) are being investigated (Figure 3).

The experimental performance assessments are executed by means of small-scaled Push-Out tests. Due to technical and geometrical aspects, the various test series partially differ in terms of the number of shear transmission points per shear joint as well as in terms of the number of shear joints (symmetric assemblies with one shear joint respectively double symmetric assemblies with two shear joints). In order to ensure the comparability of the individual test series, all experimental results are related to a single shear transmission point. Thus, not only conclusions about the various joint typologies become possible, but also values for further structural computations can be gained (Figure 3).

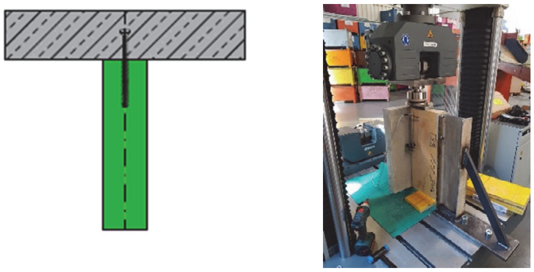

Figure 3: *Examined composite assemblies*

2.2.1 Discussion of experimental test results

Assessing the gained test results with focus on the spruce LVL assemblies' significant diversities, but also similarities within the individual test series can be identified.

Concerning the application of beech LVL assemblies coherent test results in conjunction with the spruce LVL assemblies can be observed. With the initial objective to evaluate the general suitability of hardwood LVL (beech) in comparison to softwood LVL (spruce), the conducted test series are carried out with a smaller amount of respective specimen (3 specimen in each case). As a consequence of this, the gained test results are likely to be less statistically significant and are accompanied by a simultaneously increased scattering compared to the spruce LVL assemblies, but also show the quantitative promising trends as to be expected. The increased material stiffness of hardwood beech LVL further leads to increased mechanical properties of the examined assemblies.

https://doi.org/10.52202/069179-0437

With respect to the application of crossed screw typologies a reduced increase of the load-bearing capacity in comparison to not crossed screw typologies can be observed. In conclusion, the doubling of screws per shear transmission point only leads to a 33% higher maximum load $F_{max,k}$. So, the application of screw typologies with a pure tensile load transfer can be described as the more efficient variation compared to the application of screw typologies with a combined tensile/compressive load transfer.

By the application of notch typologies, the maximum loads $F_{max,k}$ as well as the slip moduli $K_{ser,mean}$ can be increased noticeably. A significant influence of the notch depth cannot be observed thereby.

3 CONCEPTUAL FEASIBILITY STUDIES

Technically, the ribbed timber-concrete composite floor is planned as a prefabricated component. These elements can be installed completely on the construction site or subsequently assembled and concreted on site.

The structural design idea of timber-based composite constructions is founded on the utilization of joints between the single composite layers to reach an optimized application of each used composite material.

The research project includes design concepts, feasibility studies and performance assessments of the components in order to improve the overall performance. Based on the results of the performance assessments and on accompanying computation approaches (shear analogy method according to DIN EN 1995-1-1/NA [9] respectively gamma-method according to ÖNORM EN 1995-1-1 [10]) different types of composite floors are developed and compared with each other.

A comparative parameter study is done with the aim of finding a resource-efficient solution for a single-span floor system with a total length up to 12 meters (between 8m, 10m and 12m) considering fire resistance R90 (see Figure 4 as an example for a span of 8.00m).

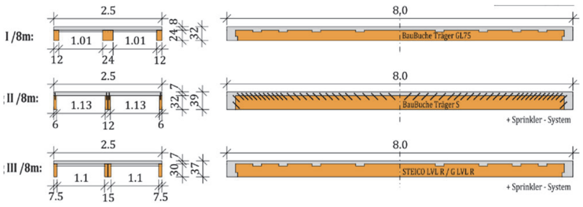

***Figure 4:** Optimized LVL-RC composite floor structures for 8m with various connection notches and screws [6]*

The resource efficiency is investigated in terms of the cross-sectional dimensions, the constellation of the materials and the kind of connections including form-fitting notches and fasteners, which can be fixed mechanically [6].

Type I is a floor system without sprinkler, Type II is a system with sprinkler and mechanical fasteners - by hand inserted screwed connection (about 13 pc. /m^2) and type III is a system with sprinkler as well as reduced timber square sections and with notches as very strong and stiff connectors between timber and concrete - notches cut in the timber and filled with concrete.

A significant part in the optimization of the floor systems is using the cost-efficient quantity of timber. This means Beech-LVL ribs instead of the massive cross-laminated timber (CLT) elements. This offers advantages especially in terms of reduced resource consumption.

With regard to the material cost calculation, it should be mentioned that only the material prices are actually calculated. It makes sense to carry out a material cost calculation. The decisive factor here is that only the material costs are evaluated in monetary terms and this is not a detailed cost calculation. Furthermore, the relationship between resource efficiency and cost efficiency for the ranges investigated becomes apparent.

For this purpose, reference values for cubic meter prices of LVL and reinforced concrete are obtained.

With the help of the already determined amount of resources per floor element, it is possible to make a rough cost calculation for a floor element or to roughly determine a price per square meter for a LVL-concrete composite floor of the respective span. It should be noted that additionally required materials after the installation of the individual ceiling elements are not taken into account depending on the constructive system.

Additionally, the material costs for the different solution variants are determined, the most cost-efficient solution can be determined.

Moreover, costs for an active fire protection system (sprinkler system) are included in the calculation, if this is necessary to be able to comply with the fire protection requirements. In this case, the sprinkler system is purely an acquisition cost without the maintenance costs. Although these costs are not directly material costs, they must be taken into account so that all solutions can be considered equal and thus remain comparable with each other [6].

By including a sprinkler system, the amount of timber can be reduced to a minimum, so that just the verifications of the design for the normal state ("cold-state design") are fulfilled. This optimization of the timber cross-section results in the use of narrow but high ribs. However, if the joint between timber and concrete is to be achieved via shear notches, a minimum width of the LVL ribs is required, otherwise the notch verifications according to [11] cannot be fulfilled. Notches are basically suitable for new buildings and an efficient composite variant. No additional resources are required, production is simple and cost efficient, only a small number of notches is needed and no additional personnel is required in the manufacturing process. In the case of screws, the rib width can be further reduced to 60mm if the verification permits. According to the approval, an edge distance of 30mm is required. In the case of fasteners, a large number are

https://doi.org/10.52202/069179-0437

required and the manpower required for setting the screws should not be underestimated either. However, as already mentioned, this is not taken into account in the material cost calculation. But due to the fact that the costs for the LVL ribs make up the main part of the material costs of the floor element and that minimum timber cross-sections are possible due to the joint via screws, a resource- as well as cost-efficient solution is also possible with screws for new buildings (see Figure 5; Solution II/8m). However, it should be mentioned here again that by minimizing the timber cross-section, an extinguishing system is mandatory to meet the fire protection requirements. And the installation of an extinguishing system is, of course, inevitably associated with an expenditure of resources, but it is often a basic requirement in high-rise construction. Comparing the concrete slab, it results for 12m to 10m span-width a reduced thickness of the slab by 3cm (from 11cm to 8cm), comparing a span of 8m, hardly no further reduction is possible. The reason for this is either the minimum thickness of 7cm specified in the approval, as well as the vibration verification according to Eurocode 5 [10] which is no longer fulfilled with a further reduction.

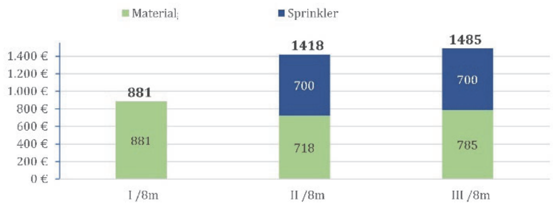

Figure 5: *Comparison of material cost calculation for 8m with various connection notches and screws [6]*

3.1 TIMBER-STEEL FIBER CONCRETE-COMPOSITE

In addition to the studies presented above, the verifications of the load-bearing capacity and serviceability are carried out on modelling bending beam floor [8]. The dimensions are chosen in such a way that the verifications of the load-bearing capacity and serviceability go out with the tests carried out. A brief overview of the most important data for this study of the timber-fiber-reinforced concrete beam floor is below mentioned:

Dimensions of the wooden beams C24: width 16cm, height 26cm, span of the beams: 6m

Height of the concrete layer C25/30: 7cm

Residential building; service class 1

Fasteners Composite screws ACC 8.0 x 165 screwed at an angle of 45°, 3 rows of screws per timber beam, screw-in depth in the timber: 7.1cm

Thickness of the formwork: 2.5cm

The cross-section is shown below, the beam spacing is 65cm, therefore all verifications are carried out for a 65cm wide cross-section.

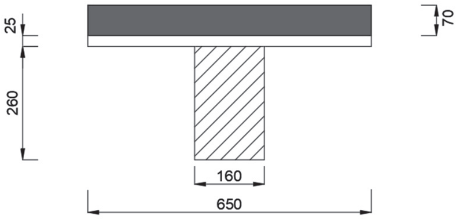

Figure 6: *Composite floor structures connection with screws [8]*

Based on the results, it can be seen that the fiber-reinforced concrete is the most stressed cross-section. Therefore, it is important to ensure that the bending moment in the fiber-reinforced concrete cross-section is reduced to a minimum, if possible, while at the same time increasing the normal force.

In the present example, the verifications of load-bearing capacity (ULS) and serviceability (SLS) are fulfilled for a fiber-reinforced concrete T2 according to the ÖBV guideline [3] and L1-0.6/ L2-0.9.

Finally, different classes of fiber-reinforced concrete will be compared and the effects on utilization or the number of fasteners will be presented. The aim of the study is to keep the number of fasteners as low as possible while maintaining an economical fiber-reinforced concrete class.

First, a reduction of the fiber-reinforced concrete layer thickness of 6cm is investigated. The fastener spacing is 25cm minimum and 80cm maximum. This results in 70 screws, which corresponds to a reduction of 40 screws per meter of slab strip. At the same time, the utilization is 92% according to the German guideline [4], which is authoritative.

In a further step, a fiber-reinforced concrete of class T3 according to the Austrian guideline [3] is considered in more detail. Here, a 7cm thick fiber-reinforced concrete layer is again assumed and a screw spacing of 15cm in the minimum and 60cm in the midspan. The only change compared to the original configuration is the design value of the post-cracking tensile strength of 0.31N/mm². Thus, the use of screws results in a utilization of 84% compared to 86%. A fiber-reinforced concrete of class T4 would produce a utilization of 81%. Thus, the difference in design is not too great when changing the fiber-reinforced concrete class alone.

If the minimum lanyard spacing is increased to 25cm and the maximum to 80cm as well as using a fiber concrete class T4 and increasing the tensile strain in the cross section from 0.9 to 1.5‰, an equilibrium condition with utilization of 98% is obtained. This means that with a fiber concrete two classes higher and a higher utilization, fasteners can be saved, in this case 40 pieces.

As a final optimization step, an increase of the fiber concrete class from L1-0.6 or L2-0.9 to L1-0.9 or L2-1.2 is also investigated when considering the German guideline [4]. Here, the utilization in the fiber-reinforced concrete cross-section also changes from 89 to 87%. Under the same boundary conditions, a saving in connection material would only be possible with a fiber-reinforced concrete class three classes higher.

Table 1 summarizes the decisive results of the different optimization variants. It should be noted, however, that these results only refer to the example given here.

In summary, increasing the fiber-reinforced concrete class has very little effect on the load-bearing capacity of the fiber-reinforced concrete cross-section. A more effective way to save fasteners, especially screws, is to reduce or optimize the thickness of the fiber-reinforced concrete layer. However, when the concrete thickness is reduced, the compressive stresses are increased. Thus, depending on the application and the given boundary conditions, it must be decided which variant, fiber-reinforced concrete or reinforced concrete, is to be used.

Table 1: *Overview of optimization*

Optimization variant	Number of screws	Change in utilization
Reference example T2 or L1-0.6, L2-0.9	110	0%
Thickness of the fiber concrete layer 6cm	70	+3%
Fiber concrete T3	110	-2%
Fiber concrete T4	70	+12%
Fiber concrete L1-0.9 or L2-1.2	110	-2%

In this study, only a fiber concrete with 25kg/m³ steel fibers is considered. Subsequently, the question is how big the differences are between the two guidelines with a fiber content of 20 or 30kg/m³. Further research questions on this topic would be how the combination of plastic fibers with steel fibers affects the load-bearing capacity and shrinkage behavior. The use of steel fibers in lightweight concrete would also be a useful option when used in timber-fiber-reinforced concrete composite structures in order to reduce the deadweight of the floor. In order to verify the calculations of timber-fiber-reinforced concrete composite floors, both fiber-reinforced concrete tests and tests on timber-fiber-reinforced concrete composite floors with the same fiber-reinforced concrete would be useful in a further step. Thus, a classification of the fiber-reinforced concrete according to Austrian and German guidelines would be available and the effects in the ultimate load of the composite floor would be visible.

4 CONCLUSIONS

The experimental performance assessments of spruce LVL assemblies as well as of beech LVL assemblies generally show promising results for an application of LVL products in composite floor systems. Also concerning the substitution of conventional reinforced concrete (RC) through steel fiber concrete (SFC), a general suitability can be observed.

The conceptual feasibility studies, based on the results of the performance assessments and on accompanying computation approaches, show the capabilities in the application of LVL products in composite floor systems. Consequently, the presented results enable engineers, as well as builders and planners, to further strengthen the implementation of timber-based composites within modern building applications.

A significant part in the optimization of the floor systems is using the cost-efficient quantity of timber. This means Beech-LVL ribs instead of the massive cross-laminated timber (CLT) elements. This offers advantages especially in terms of reduced resource consumption.

ACKNOWLEDGEMENT

The research project is a collaborative effort of the ITI/TU Wien and the Schmid Schrauben Hainfeld Ltd. The authors gratefully acknowledge the support of the Schmid Schrauben Hainfeld Ltd. and the TU Wien, Austria.

REFERENCES

[1] A. Teischinger, R. Sting and G. O. Praxmarer, 15 07 2019. [Online]. Available: http://www.proholz.at/news/news/detail/holzbauanteil-in-oesterreich-ein-viertel-des-hochbau-aufkommens-bereits-aus-holz/. [Accessed 26 10 2019].

[2] Gruber, E., Gutmann, R., Huber, M., & Oberhuemer, L., *Leistbaren Wohnraum schaffen-Stadt weiter bauen: Potenziale der Nachverdichtung in einer wachsenden Stadt: Herausforderungen und Bausteine einer sozialverträglichen Umsetzung,* Kammer für Arbeiter und Angestellte für Wien, 2018.

[3] ÖBV, *Richtlinie: Faserbeton,* Vienna: Österreichische Vereinigung für Beton- und Bautechnik, 2018.

[4] DAfStb, *Erläuterungen zur DAfStb-Richtlinie Stahlfaserbeton,,* Bochum : Deutscher Ausschuss für Stahlbeton, 2014.

[5] "European Technical Assessment 18/0829 Schmid Schrauben RAPID T-Con Wood-concrete composite slab with dowel-type fasteners," EOTA - European Organisation for Technical Assessment, [Online]. Available: https://www.eota.eu/etassessments/8378. [Accessed 11 March 2023].

[6] P. Rädler , *Master's thesis: Resource-efficient timber-concrete composite floors for use in the timber high-rise buildings,* Vienna: Department of Structural Design and Timber Engineering, Vienna University of Technology, 2018.

[7] S. Zahirovic, *Master's thesis: Structural behavior of laminated veneer lumber fiber concrete composite floors,* Vienna: Department of Structural Design and Timber Engineering, Vienna University of Technology , 2019.

[8] A. Blaha, *Master's thesis: Zum Einsatz von Holz-Faserbeton-Verbunddecken: Theoretische und experimentelle Untersuchungen,* Vienna: Department of Structural Design and Timber Engineering, Vienna University of Technology, 2021.

[9] German Institute for Standardisation, "DIN EN 1995-1-1/NA - National Annex – Nationally determined parameters – Eurocode 5: Design of timber structures – Part 1-1: General – Common rules and rules for buildings," 2013.

[10] Austrian Standards, *ÖNORM EN 1995-1-1 - Design of timber structures - Part 1-1: General - Common rules and rules for buildings (consolidated version),* 2019.

[11] Schönborn, F., Flach, M., & Feix, J., "Bemessungsregeln und Ausführungshinweise für Schubkerven im Holz-Beton-Verbundbau," *Beton- und Stahlbetonbau,* vol. 106(6), pp. 385-393, 2011.

https://doi.org/10.52202/069179-0437